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ELECTRONICS | ORIGINAL ARTICLE

Multiuser Detection in Shadowed Fading Channels with Impulsive Noise

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ABSTRACT

In direct sequence-code division multiple accesses systems (DS-CDMA), the signals are transmitted over multipath channels that introduce fading. Multipath fading along with multiple access interference and inter-symbol interference degrades the system performance. Further, simultaneous presence of multipath fading and shadowing leads to worsening of wireless channels. Moreover, experimental results have confirmed the presence of impulsive noise in wireless mobile communication channels. Hence, this paper presents a technique for multiuser detection in DS-CDMA systems over shadowed fading channels in presence of impulsive noise. Approximate expression for average probability of error of an M-decorrelator is derived, for the demodulation of binary phase shift keying (BPSK) signals over shadowed fading channels, by modeling the channel with generalized K (GK) distribution. A new M–estimator is proposed for robustifying the detector and its performance is also studied and analyzed by evaluating probability of error with the derived expression. Simulation results reveal that the proposed multiuser detector performs better in fading and shadowing with heavy-tailed impulsive noise.

Keywords: Multiuser detection; fading channel; impulsive noise; GK distribution; probability of error.

I. INTRODUCTION

Recent research has explored the potential benefits of evolutionary optimization algorithms and their application to multiuser detection (MUD) for direct-sequence code division multiple access (DS-CDMA) systems [1]-[4]. An adaptive robust MUD technique for CDMA by implementing Huber's M-estimator using genetic algorithm (GA) is presented in [3] and shown that it is robust against heavy-tailed impulsive noise. Recently, particle swarm optimization (PSO) algorithm has been applied for the MUD [4] to detect received data bit by optimizing an objective function.

The generalized-K (GK) fading channel has been received considerable attention as it can provide a good fit to different fading environments such as Nakagami-m and Rayleigh-Lognormal [5]. Experimental results have confirmed the presence of heavy-tailed impulsive noise in outdoor mobile communication channels, in radar and sonar systems and in indoor wireless communication channels [6]. Hence, this paper presents the implementation and performance analysis of proposed based M-estimator [7], [10], which performs well in the heavy-tailed impulsive noise, using PSO algorithm.

II. SYSTEM MODEL

Consider an L-user synchronous CDMA system, where each user transmits information by modulating a PN sequence over a single-path GK fading channel. The received signal over one symbol duration can be modeled as [8]

$$r(t)=\Re\left\{\sum_{l=1}^{L}\sum_{i=0}^{M-1} b_l(i)\alpha_l(t)e^{j\phi(t)}s_l(t-iT_s-\tau_l)\right\}+n(t) \quad (1)$$

where $\Re\{\cdot\}$ denotes the real part, M is the number of data symbols per user in the data frame of interest, T_s is the symbol interval, $\alpha_l(t)$ is the time-varying

fading gain of the l[th] user's channel, $\phi_l(t)$ is the time-varying phase of the l[th] user's channel, $b_l(i)$ is the i[th] bit of the l[th] user, $s_l(t)$ is the normalized signaling waveform of the l[th] user and $n(t)$ is assumed as a zero-mean complex two-term non-Gaussian noise [9].

For synchronous case (i.e., $\tau_1 = \tau_2 = ... = \tau_l = 0$), assuming that the fading process for each user varies at a slower rate that the magnitude and phase can taken to be constant over the duration of a bit, the received signal can be expressed in matrix notation as [9]

$$\underline{\boldsymbol{r}}(i) = \underline{A}\underline{\boldsymbol{\theta}}(i) + \underline{\boldsymbol{w}}(i) \qquad (2)$$

where $\underline{\boldsymbol{r}}(i) \triangleq \left[\boldsymbol{r}_1(i),...,\boldsymbol{r}_N(i)\right]^T$,

$\underline{\boldsymbol{w}}(i) \triangleq \left[\boldsymbol{w}_1(i),...,\boldsymbol{w}_N(i)\right]^T$ and

$\underline{\boldsymbol{\theta}}(i) \triangleq \frac{1}{\sqrt{N}}\left[\boldsymbol{b}_1(i)\boldsymbol{g}_1(i),...,\boldsymbol{b}_L(i)\boldsymbol{g}_L(i)\right]^T$.

Here, $\boldsymbol{w}_n(i)$ is a sequence of independent and identically distributed (i.i.d.) complex random variables whose in-phase and quadrature components are independent non-Gaussian random variables, $\boldsymbol{g}_l(i)$ is the l[th] channel fading coefficient and $\underline{A} \triangleq [\underline{a}_1, \underline{a}_2, ..., \underline{a}_L]$ with $\underline{a}_l \triangleq [a_1^l, a_2^l, ..., a_N^l]$.

It is assumed that the signal of each user arrives at the receiver through an independent, single-path fading channel. For the shadowed fading channels, $\alpha_l(i)$ are i.i.d. random variables with GK distribution given by [12]

$$p_\alpha(\alpha_l) = \frac{2}{\Gamma(m)\Gamma(\mu)}\left(\sqrt{\frac{m\mu}{\Omega_0}}\right)^{m+\mu} \alpha_l^{\frac{m+\mu}{2}-1} K_{m-\mu}\left(2\sqrt{\frac{m\mu}{\Omega_0}}\alpha_l\right) \qquad (3)$$

where, m is the Nakagami fading parameter that determines the severity of the fading, μ represents the shadowing levels, Ω_0 is the average SNR in a shadowed fading channel, $K_\xi(\cdot)$ is the modified Bessel function and $\Gamma(\cdot)$ is the Gamma function [9]

In M-estimates, unknown parameters $\underline{\theta}_1, \underline{\theta}_2, ...\underline{\theta}_L$ are solved by minimizing a sum of function, $\rho(\cdot)$ of the residuals [9]

$$\hat{\underline{\boldsymbol{\theta}}} = F\left(\theta_l(i)\right) = \underset{\underline{\boldsymbol{\theta}} \in C^L}{\arg\min} \sum_{n=1}^{N}\left\{\rho\left[\Re\left(\boldsymbol{r}_n(i) - \sum_{l=1}^{L}[\underline{A}]_{nl}\theta_l(i)\right)\right] + \rho\left[\Im\left(\boldsymbol{r}_n(i) - \sum_{l=1}^{L}[\underline{A}]_{nl}\theta_l(i)\right)\right]\right\} \qquad (4)$$

where $\rho(\cdot)$ represents a specific penalty function that is symmetric positive-definite with a unique minimum at zero, and is chosen to be less increasing than square, $r_n(i)$ and $\theta_l(i)$ are the n[th] and l[th] elements of the vectors $\underline{\boldsymbol{r}}(i)$ and $\underline{\boldsymbol{\theta}}(i)$ respectively, $[\underline{A}]_{nl}$ is the nl[th] element of the matrix $\underline{A}$, and $\Im(\cdot)$ denotes imaginary part. This paper considers the modified-Hampel based M-estimator to implement an M-decorrelating detector with penalty function [7]

$$\rho_{MH}(x) = \begin{cases} \frac{x^2}{2} & for\ |x| \le a \\ \frac{a^2}{2} - a|x| & for\ a < |x| \le b \\ -\frac{ab}{2}\exp\left(1 - \frac{|x|^2}{b^2}\right) + d & for\ |x| > b \end{cases} \qquad (5)$$

where a, b and d are constants that depend on the robustness of the estimator [7].

III. PSO BASED M-DECORRELATING DETECTOR

PSO is a swarm intelligence method for global optimization modeled after the social behavior of bird flocking and fish schooling [4]. In PSO algorithm the solution search is conducted using a population of individual particles, where each particle represents a candidate solution to the optimization problem (3). Each particle keeps track of the position of its individual best solution (called as pbest), $\mathbf{p}_d^{best} = [p_{d_1}^{best}, ..., p_{d_L}^{best}]$ and the overall global best solution (called as gbest), $\mathbf{g}^{best} = [g_1^{best}, ..., g_L^{best}]$ among p bests of all the particles in the population represented as $\mathbf{p}_d^{it} = [p_{d_1}^{it}, ..., p_{d_L}^{it}]$, where $\mathbf{p}_d^{it}$ is the d[th]

particle in the it^{th} iteration, d = 1, 2, …, N_p, it = 1, 2,…, N_{it}, N_p is the number of particles, and N_{it} is the maximum number of iterations. Corresponding to each position, the particle velocity is $v_d^{it} = [v_{d_1}^{it}, \ldots, v_{d_L}^{it}]$ [2], [4]. The steps involved in the PSO based M-decorrelating detector's implementation are [2], [3], [4]:

Step 1: Compute the decorrelating detector output, $\underline{\boldsymbol{\theta}}^0 = \underline{R}^{-1}\underline{A}^T\underline{r}$. Here, $\underline{R}\left(\triangleq \underline{A}^T\underline{A}/N\right)$ is the normalized cross-correlation matrix of signature waveforms of all users.

Step 2: Initialization: The output of decorrelating detector is taken as input first particle $\mathbf{d}_1^0 = \underline{\boldsymbol{\theta}}_1^0$.

Step 3: Fitness evaluation: The objective function (3) is used to find the fitness vector by substituting residuals. Local best position $\mathbf{p}_d^{best}$ is recorded by looking at the history of each particle and the particle with lowest fitness is taken as $\mathbf{g}^{best}$ of the population.

Step 4: Update the inertia weight by using the decrement function $w^{it} = \beta w^{it-1}$, where $\beta < 1$ is the decrement constant.

Step 5: Update the particle velocity by using the relations

$$v_d^{it+1} = w^{it+1} \times v_d^{it} + \overbrace{c_1 \times \mu_1 \times \left(\mathbf{p}_d^{best} - \mathbf{p}_d^{it}\right)}^{private\,thinking\,of\,the\,particle} + \underbrace{c_2 \times \mu_2 \times \left(\mathbf{g}^{best} - \mathbf{p}_d^{it}\right)}_{social\,thinking\,of\,the\,particle} \quad (6)$$

$$\mathbf{p}_d^{it+1} = \mathbf{p}_d^{it} + v_d^{it+1} \quad (7)$$

where c_1 and c_2 are the acceleration constants representing the weighting of the stochastic acceleration terms to pull the particle to pbest and gbest. μ_1 and μ_2 are random numbers that are uniformly distributed between 0 and 1. Particle position is updated according to (6). Particle velocity is limited by the maximum velocity $\mathbf{v}^{\max} = [v_1^{\max}, \ldots, v_2^{\max}]$.

Step 6: The individual best particle position is updated by following rule: $\begin{array}{l} if\ F\left(\mathbf{p}_d^{it}\right) \le F\left(\mathbf{p}_d^{best}\right) \\ then\ \mathbf{p}_d^{best} = \mathbf{p}_d^{it} \end{array}$.

Step 7: $\mathbf{g}^{best}$ is the global best particle position among all the individual best particle positions $\mathbf{p}_d^{it}$ at the it^{th} iteration such that $F\left(\mathbf{g}^{best}\right) \le F\left(\mathbf{p}_d^{it}\right)$.

Step 8: The above steps are repeated until the maximum number of iterations has been reached.

The computed $\mathbf{g}^{best}$ value is used to evaluate average probability of error of BPSK demodulator, over GK fading channel, by an approximate expression given by

$$\overline{P_e^1} = F.\frac{1}{2}\alpha^{-0.5l\beta^{-1}}\Gamma\left(\frac{1+d+l}{2}\right)\Gamma\left(\frac{1-d+l}{2}\right) \cdot \exp\left(\frac{\beta^2}{8\alpha}\right)W_{-0.5l,d}\left(\frac{\beta^2}{4\alpha}\right) \quad (8)$$

where m is the Nakagami fading parameter that determines the severity of the fading, μ represents the shadowing levels, Ω_0 is the average SNR in a shadowed fading channel $F = \frac{2}{\Gamma(m)\Gamma(\mu)}\left(\sqrt{\frac{m\mu}{\Omega_0}}\right)^{m+\mu}$, $d = m - \mu$, $l = \frac{m+\mu}{2} - 1$, $\alpha = \frac{1}{v^2\left[R^{-1}\right]_{11}}$ and $\beta = 2\sqrt{\frac{m\mu}{\Omega_0}}$ and $W_{\lambda,\gamma}(\cdot)$ is the Whittaker function [13].

TABLE I. PSO PARAMETERS USED FOR SIMULATION

Parameter	Value
Number of particles, N_p	20
Maximum number of iterations, N_{it}	100
Acceleration constants c_1 and c_2	2
Maximum velocity of the particles $\left\lvert v_l^{\max}\right\rvert$ for all users	2
Initial inertial weight, w	1
Decrement constant, β	0.99

IV. SIMULATION RESULTS

In this section, the performance of M-decorrelating detector is presented by computing (7) for for different values of fading parameters and shadowing levels with least-squares, Huber, Hampel and modified-Hampel penalty functions. The PSO parameters used for simulation are presented in Table I. The value of $\mathbf{g}^{best}$ is computed for specified penalty functions and is used to compute the average probability of error (7) of BPSK signals.

In Fig. 1 and Fig. 2, the average probability of error versus the signal-to-noise ratio (SNR) corresponding to the user 1 under perfect power control of a synchronous DS-CDMA system with six users (L = 6) and processing gain, N = 31 is plotted for moderate impulsiveness (ε = 0.01) of noise, m = 1, μ = 1. Similarly, the average probability of error is plotted.

In Fig. 3 and Fig. 4 with highly impulsive noise (ε = 0.1) and m = 1, μ = 1. These simulation results show that the decorrelating detector with proposed estimator based detector performs well even in highly impulsive noise when compared to least-squares, Huber and Hampel estimator based detectors.

V. CONCLUDING REMARKS

Multiuser detection technique for DS-CDMA systems over GK fading channels using PSO was presented in this paper. An objective function, which is a sum of less rapidly increasing function of residuals, was used to obtain optimum estimates. An M-decorrelator is implemented with different influence functions. Simulation results shows that the proposed M-decorrelator performs better when compared to least-squares, Huber and Hampel estimator based detectors.

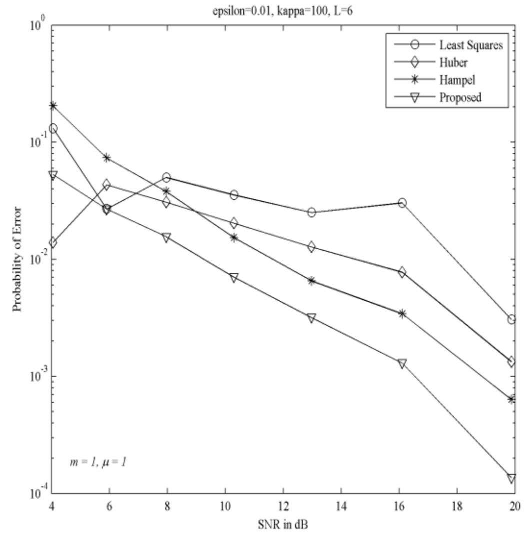

Fig.1 Average probability of error versus SNR for user 1 for linear multiuser detector, minimax detector with Huber, Hampel and proposed M-estimator in synchronous CDMA channel with impulse noise, N = 31, ε = 0.01, m = 1, μ = 1.

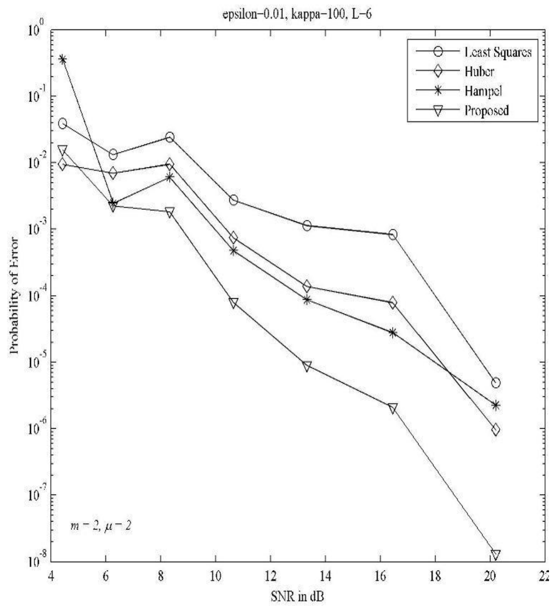

Fig.2 Average probability of error versus SNR for user 1 for linear multiuser detector, minimax detector with Huber, Hampel and proposed M-estimator in synchronous CDMA channel with impulse noise, N = 31, ε = 0.01, m = 2, μ = 2.

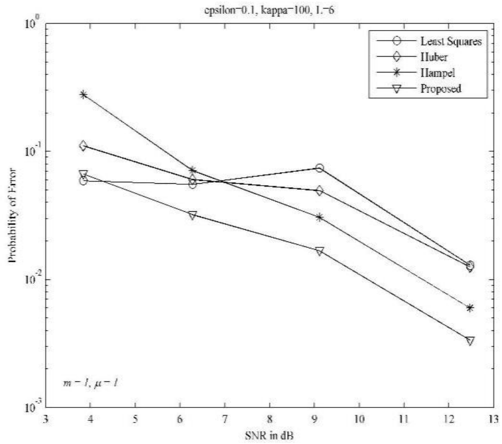

Fig.3 Average probability of error versus SNR for user 1 for linear multiuser detector, minimax detector with Huber, Hampel and proposed M-estimator in synchronous CDMA channel with impulse noise, N = 31, $\varepsilon = 0.1$, m = 1, μ = 1.

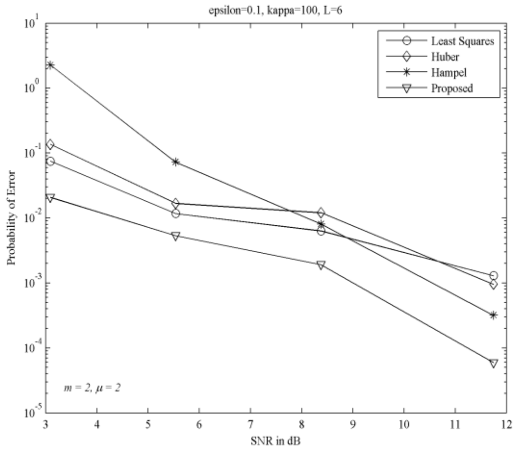

Fig.4 Average probability of error versus SNR for user 1 for linear multiuser detector, minimax detector with Huber, Hampel and proposed M-estimator in synchronous CDMA channel with impulse noise, N = 31, $\varepsilon = 0.1$, m = 2, μ = 2.

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